Collaborative Exploration of Rich Content in Support of Knowledge Re-use

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Summary

A/E/C Team members, while collaborating on building projects, rely on past experiences and content through the use of project design archives (whether in paper or digital format). This leads to underutilization of potential knowledge, as decision-making of data, information, and knowledge reuse is limited by access to these archives, due to sheer size and inconvenient presentation. This paper presents an integrated solution that leverages two technologies CoMem (Corporate Memory) and iRoom (interactive Room) developed at Stanford. This addresses critical limitations, i.e., content, context, visualization and interactivity, constraining the process of collaborative exploration towards knowledge reuse and decision-making.

1. Introduction

Architecture, Engineering and Construction (A/E/C) Teams and individuals involved in the design process often collaborate with team members with broad experience gained from previous projects in the firm, so they attempt to share and reuse their knowledge. This collaborative knowledge reuse from past experiences involves exploration of design content stored in corporate project design repositories and archives either in digital or paper format. However, these design archives do not capture the entire design process thereby resulting in loss of contextual information. These archives also tend to store large amounts of unorganized but nevertheless, very rich content (blue-prints, pictures, calculations etc.). The process of collaboration in such a setting entails participants looking at large amounts of decontextualized design data over limited physical and visual space with team-members often making inaccurate assumptions about design process decisions and justifications.

In this paper, we identify issues that limit the process of collaborative exploration of these project archives and repositories and broadly classify them into three categories: *content* based limitations, *context* based limitations and *visualization* limitations. We introduce two technologies Corporate Memory and iRoom that address these limitations as integrated systems. Corporate Memory (CoMem™) (Fruchter and Demian 2002 a, b) is a collaborative technology developed by the PBL Lab at Stanford University to support the process performed by a single user to reuse of knowledge stored in corporate project design databases. The iRoom architecture has been developed through the Interactive Workspaces project by the Human Computer Interaction (HCI) group at Stanford University (Johanson et al 2002 a, b) that investigates human interaction in ubiquitous computing environments comprising of large displays. We further hypothesize that an integration of these two technologies will result in a workspace that is ideally suited to the process of collaborative exploration and addresses the need for all participants to explore and manipulate rich content concurrently and effectively in support of reuse. We describe the technical details of this process of integration and discuss the benefits of the proposed system through a scenario.

2. Motivation

Consider the following scenario that highlights the deficiencies in the collaboration process of exploration and knowledge re-use in A/E/C teams. In the scenario, an inter-disciplinary team meets in a conference room to discuss preliminary design aspects of a university building.

2.1 Project Teamwork Scenario

Dan, Bo, and Andrea are the architect, engineer, and construction manager, respectively, in an A/E/C firm working on the design for a proposed 30,000 sq. ft. building for the Engineering department of Pacific University, on the Oregon coastline. The timeframe for this design-build project is short – approximately 12 months – so they've been working together regularly to speed up the design process. They have agreed to meet to discuss aspects of the building design and construction (Figure 1).

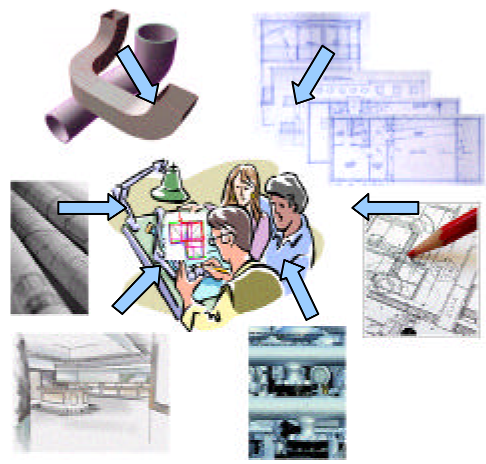

Figure 1: State of practice. Paper-based project repositories and archives are ill suited for knowledge exploration and reuse in collaborative, inter-disciplinary concept development.

During their conversation, they discuss the floor height constraint and how it will relate to the HVAC system. Bo proposes exposing the ductwork along the walls of the building's atrium, rather than having them cut into the structure and plenum space in the hallways. Dan immediately rejects the idea, explaining that exposed ductwork would ruin the architectural concept of the atrium. Andrea interrupts to describe an exposed ductwork system she worked on in a past project of similar size at Coastal University on the Atlantic coast. She thinks it may hold the solution to Dan's concerns, and begins to sketch out how the ductwork was constructed, and how it complemented the architectural concept. Dan has a difficult time understanding Andrea's sketches, so Bo leaves to retrieve material from the project Andrea is describing. He has difficulty searching through the company's extensive digital and paper file repositories, specifically, trying to determine which files relate directly to the ductwork system in the old project. After twenty minutes of frustrating search, he returns with a roll of MEP blueprints. Dan and Andrea search through the blueprints and find a few pages with details that document the exposed HVAC. Due to the schematic nature of the drawings, Dan has difficulty visualizing the entire system, and how it relates to other aspects of the building. In searching through the documents, they've spread on the conference table, and have difficulty referring back to the material that they'd already found. Dan becomes frustrated trying to correlate data among layers of blueprints and other related documents, and is still concerned that the differences in the architectural concepts are too different to make a comparison between them. He explains that he has a hard time linking all the pieces together to understand how they evolved, and he wants to know how other aspects of the building design were affected by the choice of exposed HVAC. Dan remains unconvinced and argues that the exposed ductwork examples Bo and Andrea have described don't translate to the context of the current project, and dismisses this option.

2.2 State of Practice: Knowledge Retrieval and Exploration Affordance Limitations

Based on the above scenario, we identify critical limitations constraining the described process of collaborative exploration and decision-making through knowledge reuse:

- **Content Based Limitations** – Current archives tend to be large, incomplete and disjunct making retrieval and exploration difficult and time-consuming. This is clearly visible in the above scenario where Bo has difficulty exploring the company's entire project archive and thereby ends up retrieving decontextualized information from a past project with the key steps in the design decision process missing.
- **Contextual Limitations** –Archives of past designs do not retain sufficient context within which design decisions were reached. Little information about the design process or intermediate design versions is retained thereby leading to decontextualized design data.
- **Visualization and Interactivity Limitations** – Limitations on direct manipulation and visualization of rich content as most of these designs occupy large display spaces (digital or physical) and allow for limited manipulation resulting in a constrained interaction process. Such a constrained interaction process poses difficulty to compare retrieved documents and identify the relevance of those retrieved documents to the problem at hand. It also leads to constrained knowledge exploration as participants manipulate and explore partial information as many documents from intermediate phases are not archived and the parts of the retrieved documentation are not linked.

3. CoMem-iRoom Approach

The integrated CoMem™ and iRoom architecture presents an innovative environment that addresses the identified limitations in the process of collaborative teamwork for knowledge exploration and reuse.

CoMem™ (Corporate Memory) is a collaboration technology that facilitates context-based reuse of corporate knowledge in a single-user setting that has been developed in the PBL lab (Fruchter and Demian, 2002) for the A/E/C community. CoMem™ allows for context based visualization and exploration of large hierarchical project design databases. The Interactive Room (iRoom) architecture (Johanson, Fox and Winograd 2002) is a technology that enables communication between discipline-specific control applications running on multiple machines. By making CoMem™ the nodal application of the iRoom architecture, we extend the contextual visualization and exploration functionality provided by CoMem™ from a single-user to a multi-user interactive setting, thereby enabling collaborative exploration in project group meetings and knowledge reuse discussions.

3.1 CoMem™ (Corporate Memory):

To design CoMem™ we conducted ethnographic studies to understand the internal knowledge reuse process applied by human domain experts. We identified two reasons for the effectiveness of internal knowledge reuse:

1. Even though the expert's internal memory is very large, he is always able to ***find*** relevant designs or experiences to reuse.
2. For each specific design or part of a design he was reusing, he is able to retrieve a lot of contextual knowledge. This helps him to ***understand*** this design and apply it to the situation at hand. When describing contextual knowledge to the novice, the expert explores two contextual dimensions: the ***project context*** and the ***evolution history***.

Armed with these observations, we set out to design an external reuse system that would enable designers to:

1. Find reusable items in large corporate archives
2. Explore the project context of these items in order to understand them
3. Explore the evolution history of these items in order to understand them

3.1.1 CoMem™ modules

Based on the three reuse steps identified above – find, explore project context, explore evolution history – CoMem™ has three corresponding modules: an overview, a project context explorer, and an evolution history explorer. For each module, we investigated various radically different *metaphors*. We use *metaphor* here in a human-computer interaction sense. Metaphors increase the usability of user interfaces by supporting understanding by analogy. Modern operating systems use the desktop metaphor. Online services use shopping cart and checkout metaphors to relate the novel experience of buying online to the familiar experience of buying at a bricks and mortar store.

CoMem™ uses a ***map metaphor*** for the overview. The CoMem™ Overview Module provides a succinct "at a glance" view of the entire corporate memory. Corporate memories are usually hierarchical, where the corporation contains multiple projects, each project consists of multiple disciplines or building subsystems (structural, electrical, and so on), and each discipline contributes multiple components. This hierarchy can become very large. For example, consider a small design practice that has worked on 10 projects, each project involving 10 disciplines, each discipline contributing 20 components, with each object versioned 50 times over the course of the project. The total number of objects in the corporate memory is close to 10^5. Conventional techniques for visualizing hierarchies using nodes connected by links are inappropriate, given that the overview needs to show the entire corporate memory in a single display. CoMem™ uses the ***"squarified treemap" algorithm*** to display an overview of the corporate memory in which the hierarchy is visualized as a series of nested rectangles. The area on the map allocated to each item is based on a measure of how much knowledge this item encapsulates, i.e. how richly annotated it is, how many times it is versioned, how much external data is linked to it. Each item on the map is color-coded by a measure of relevance to the designer's current task. Currently, this relevance measure is based on textual analysis of the corporate memory.

The CoMem™ Project Context Explorer (PCE) module enables the designer to explore the project context of any item selected from the overview. This item becomes the *focal point* of the interaction. CoMem™ uses a ***fisheye lens metaphor*** for the project context explorer. A fisheye lens balances local detail with global context. This metaphor is used here to suggest that the designer is initially concerned only with the item of interest, but begins to explore the context "outwards" as necessary. Given a user-specified focal point, CoMem™ uses the ***fisheye formulation*** to assign a degree of interest to every item in the corporate memory.

Our observations show that the most striking means of transmitting knowledge from experts to novices in A/E/C design offices is through the informal recounting of experiences from past projects. Stories convey great amounts of knowledge and information in relatively few words. CoMem™ uses a ***storytelling metaphor*** for the evolution history explorer. The CoMem™ **Evolution History Explorer** (EHE) module enables the designer to explore the evolution history of any item selected from the overview - from an abstract idea to a fully designed and detailed physical component, discipline subsystem, or even entire project.

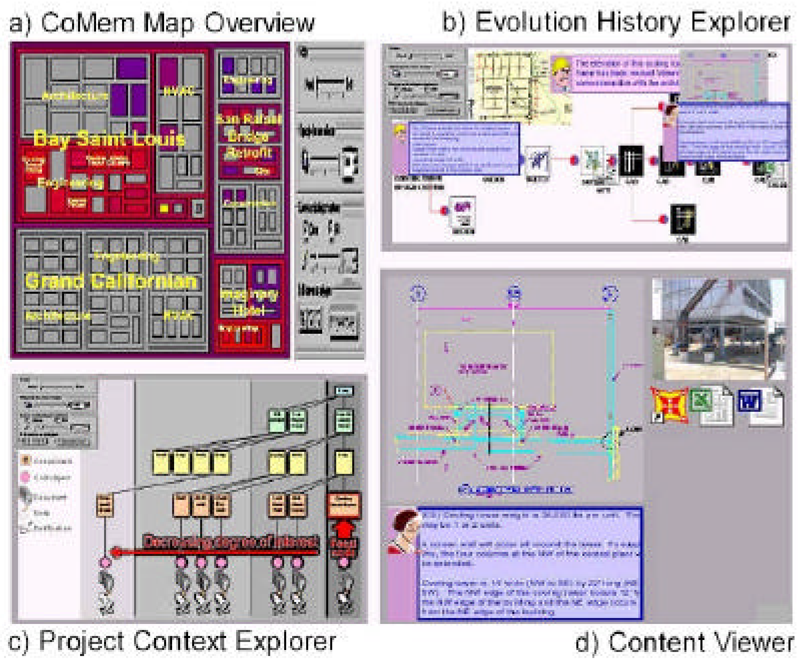

***Figure 2*: CoMem™ Modules: (a) The Map Overview provides a succinct snapshot of the entire corporate memorys; (b) The Evolution History Explorer allows the user to explore the evolution of an item before reusing it; (c) The Project Context Explorer allows the user to explore related items in the corporate memory to better understand the item being reused; (d) The Content Viewer displays the item being reused.**

We find that CoMem™ as a tool that allows us to visualize large hierarchies at one glance as well as provides the functionality to explore local context for any part of that large hierarchy. Hence CoMem™ addresses the content and context based limitations in the process of collaboration for knowledge reuse.

3.2 iRoom Architecture

The iRoom architecture has been developed by the HCI group at Stanford University as a part of the Interactive Workspaces project started in 1999 in the Human Computer Interaction (HCI) Group in the Computer Science department at Stanford University. (Johanson, Fox and Winograd 2002) The objective of the project has been to investigate human interaction with large resolution displays embedded in ubiquitous computing environments that could sustain realistic interactive use. Specifically, the objectives of such an environment would be:

- Ability to map a single defined physical location to an underlying systems infrastructure.
- Emphasis on the use of large interactive walk-up displays with touch interaction.
- Development of 'nodal' applications that could be integrated in the iRoom architecture and that emphasized the additional interactivity functionality obtained through the iRoom.
- Control processes running on different PCs to ensure seamless and smooth interaction.

The original prototype of the iRoom included a number of touch-sensitive white-board displays along sidewalls. This environment was made available to the other research groups at Stanford University that collaborate with the HCI group such as the PBL Lab.

The iRoom facilitates tasks with the following three characteristics:

- **Moving Data:** Multiple users in the room need to be able to move data among the various visualization applications running on different devices such as PCs with large screens or laptops or PDAs.
- **Moving Control:** To minimize disruption during collaboration sessions, any user should be able to control any device from his or her current location.
- **Dynamic Application Co-ordination:** Embedded nodal applications that may need to communicate with modules on other screens (machines) should have communication modules that integrate with the iRoom communication functionality.

The software infrastructure supporting the iRoom architecture is called iROS (Interactive Room Operating System). It is a meta-OS that ties together devices each having their own low-level OS. iROS has three subsystems: *Data Heap, iCrafter* and *Event Heap* addressing the three user modalities of moving data, moving control and dynamic application co-ordination. For the purposes of the CoMem™-iRoom integration we integrated iROS and the Event Heap subsystem with CoMem. The Event Heap (Johanson and Fox, 2002) is a co-ordination infrastructure for iROS derived from a tuple space model which offers inherent decoupling. It stores and forwards messages known as events, each of which is a collection of name-type-values fields. Examples of such fields in a message could be *application_name, addressed_from, addressed_to* etc. It provides a central repository to which all applications in an interactive workspace can post events. An application can then selectively choose to pick up events from the event heap that are addressed to it and decide on actions to perform locally. In general, iROS applications do not communicate directly with one another but instead communicate through the Event Heap as it helps avoid highly interdependent application components that could cause each other to clash. The Event Heap further allows decoupling of applications referentially with information being routed by attributes rather than by application name i.e. applications are referred to by attribute values and not names thereby allowing grouping and ungrouping of applications sending messages. Figure 3 illustrates the PBL Lab configuration that includes the following fixed devices:

- 3 PC Clients, with two being connected to large displays that can be smartboards for direct manipulation and or projection screens.
- An Event Heap PC
- A CoMem database PC

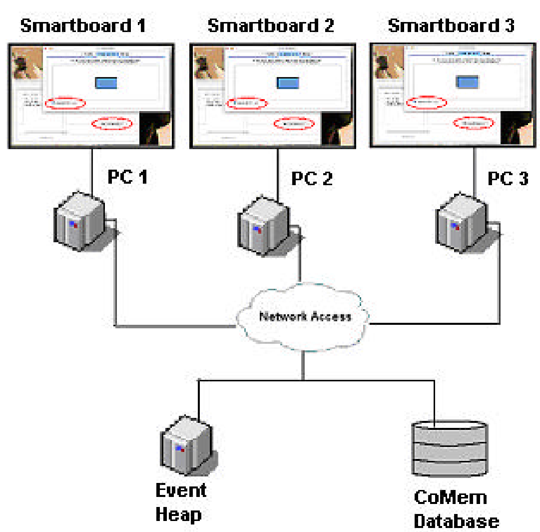

Figure 3:PBL iRoom layout – consists of 3 large displays each connected to a PC on the network. The Event-Heap and the CoMem™ Database reside on separate PCs connected to the network

3.3 CoMem™ – iRoom:

3.3.1 System Architecture:

CoMem™ embedded as a nodal application to iROS addresses the visualization and interactivity limitations constraining the collaborative knowledge reuse process as discussed in section 2.2. To help visualize the system architecture, we introduce a metaphor here – *The CoMem™-Villager* with the rationale being that individual CoMem™-villagers communicate just as villagers co-existing in a village exchanging information. Each CoMem™-Villager resides on a networked host that is a part of the iRoom architecture. The integrated CoMem™-iRoom environment is then a collection of these CoMem™-Villagers communicating with each other in the networked iRoom architecture (Figure 4). Specifically, the integrated CoMem™ – iRoom has the following system components:

- **CoMem™ – Standalone**

  This is the standalone single-user CoMem™ version that has been developed by the PBL Lab (Fruchter, Demian 2002) that was augmented with a control interface that allows users to determine specific actions and CoMem™ -Villagers on which they intend to execute those actions.
- **Action & Target Selection interface:**

  The CoMem™-Villager has an *Action and Target Selection* graphical user interface (GUI) that contains a set of menus that allow a user to select a given action and the CoMem™ -Villager on which to execute those actions. The list of actions available is dynamic and varies depending on which CoMem™ module this interface is invoked from as the set of accessible components in each module vary. For instance, the list of actions if invoked from the Overview Map would give the user a choice to open a new Project Context Explorer or a new Evolution History Explorer, where as the list of actions if invoked from the Evolution History Explorer, would give the user a choice to open a graphic, hyperlink, note, notification etc.
- **CoMem™ – Communication Module:**

  We have developed a communication module as a functional extension to the CoMem™-Standalone module as described above. This module acts as an interface between the Event Heap in iROS and CoMem™-Standalone module. The CoMem™-communication module coupled with CoMem™-Standalone and the Action-Target selection interface forms a CoMem™ -Villager implementation.
- **System Configurations Module:**

  Each CoMem™-Villager uses a configurations module that allows the user to configure the local preferences and network communications on a specific CoMem™-Villager. Specifically, the module allows for:
  - Modification of user-preferences for the usage of CoMem™ -Villager.
  - Maintenance of *public / private status* of the CoMem™ -Villager corresponding to send & receive actions. Specifically, a CoMem™-Villager in *private status* will ignore all actions and components directed towards it from other villagers and allow only one-way outgoing communication. This is necessary if a user on a *private* CoMem™ -Villager wants to explore a given CoMem™ module at length while letting other participants continue to collaborate.
  - The configurations module is also responsible for maintaining a registry of other CoMem™-Villagers currently logged into the iRoom.
- **iROS – Event Heap**

  The module of the iROS architecture used in the development of the integrated CoMem™ – iRoom architecture is the Event Heap. The event heap as described above allows for decoupling of communication between applications. This is achieved through a common communication format (tuples of the form : name-type-value) and access to all the CoMem™ – Villagers.

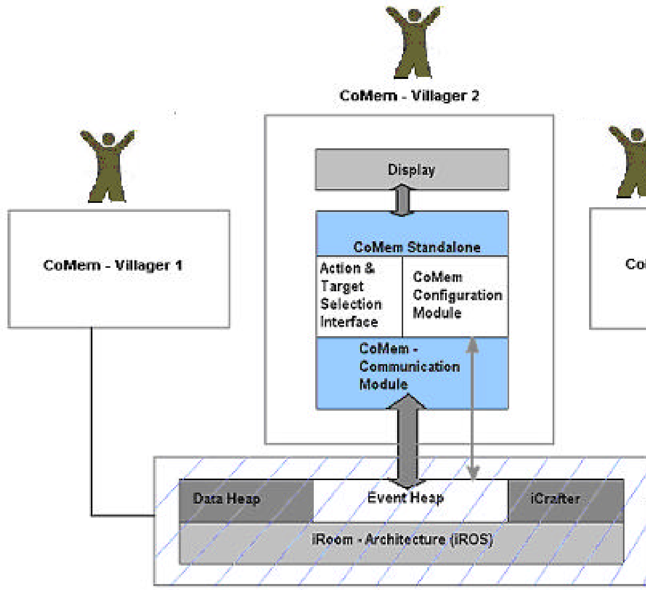

Figure 4: Integrated CoMem-iRoom System Architecture: CoMem™ –Villagers integrated with an iROS (iRoom Operating System) exchanging information through the Event Heap.

3.3.2 Communication Process:

The following interaction sequence during the communication process between two CoMem™ - Villagers, say CV1 and CV2 being used by Users A and B respectively who are trying to reuse knowledge related to "Cooling-Towers"

- User A finds component "Cooling-Tower: HVAC Vibration" to be of interest on the overview map. He further explores it and sends the Project Context Explorer of the component to User B using CV2.
- To do so, User A clicks on the "Cooling-Tower: HVAC Vibration" component on CV1. A menu displays possible actions on invocation from the Overview map, and possible destinations for display in the iRoom. This is controlled by the Action-Target Selection interface which in turn gets information about other villagers from the System Configurations Module. User A decides to send "Execute Project Context Explorer with component 'Cooling Tower' on CV2" as the action to be executed on target villager.
- This command is decomposed into two components: (1) Action that performs the task – "Execute project context explorer with component 'Cooling Tower'" and (2) Destination Villager – "CV2". These 2 components are then packaged into an Event Heap readable tuple format by CV1's communication module, and sent to the Event Heap.
- The communication module which is continuously polling the Event Heap for messages directed towards itself notices a new tuple with destination "CV2". The communication module picks up the tuple and reconstructs the packaged Action: "Execute Project Context Explorer with component 'Cooling Tower'".
- This reconstructed action is then sent to CoMem™-Standalone module of CV2 and executed.
- The Project Context Explorer with component 'Cooling Tower' is displayed on CV2.

4. CoMem™ -iRoom in Action

The following scenario describes the envisioned usage process and benefits of CoMem™-iRoom.

4.1 Project Teamwork Scenario Revisited

- *Dan the architect, Bo the engineer, and Andrea the construction manager meet to discuss the HVAC issue. Andrea retrieves from her memory the exposed ductwork system used in the Coastal University project – one of the firm's projects on which she worked two years ago. Dan has several questions: What was the impetus for switching from a plenum to exposed ductwork system? What impact did this have on the architectural design? How did the designers account for the other implications of this decision? Were any other potential solutions explored? To answer these questions, Andrea opens a CoMem-iRoom Villager in the conference room and searches for the Coastal University project and its HVAC system by entering the keyword "HVAC" (Figure 5). She opens a CoMem Overview Map on the center screen (B), and finds several items in the Corporate Map that are shaded red, indicating high relevance. She finds a component she'd like to explore, and selects it. A menu appears that displays the choice of opening an Evolution History Explorer (EHE), Project Context Explorer (PCE), or Unversioned Modeling Component (UMC). Andrea has the option of opening any of these modules on any of the Villagers in the CoMem-iRoom. She decides to open the Map component's EHE on the Villager running on the left display (A), and its Project Context Explorer on the Villager controlling the right display (C).*
- *The EHE displays that the HVAC component evolved in three primary stages during its design, and documents the points at which critical decisions were made to switch from one version to another. The documents include notes, drawings, images, and URL's from various stages in the design process. Dan decides to explore two of the versions – one before a critical decision, and one after the decision. On the EHE, he opens notes associated with them (Figure 6, A), and then opens an image associated with the first version on the center screen (B), and an image associated with the second version on the right screen (C). From these notes and images, the group determines that the HVAC system design was altered to include exposed ductwork due to height limitations in the Coastal University project's program. Bo is interested in determining how the installation of the ductwork was designed and how it evolved. Using the Villager controlling the left display, he opens a sketch link on the EHE representing an early version on the center screen (Figure 7, B) and a detail from the final version on the right screen (C).*
- *To determine how the architectural concept and other aspects of the building design were impacted by this change, Dan refers back to the PCE of the original HVAC component (Figure 8, C). The structure and color-coding of the PCE display indicates that there are two other components that have a high relevance to the HVAC design – the interior atrium of the Coastal University project, and an exposed ductwork system in the California Hotel project. Dan decides to explore both of them. He opens a CoMem Unversioned Modeling Component (UMC) for the atrium on the left screen (A). The UMC displays all components – images, drawings, notes, and URL's – that have been associated with the atrium, regardless of version. He also opens a UMC for the California Hotel project on the center screen (B).*
- *The atrium UMC displays an architectural rendering of the atrium with the exposed ductwork. It also contains a link to a message board that the team used. Dan opens the link to the message board discussion from the EHE HVAC design evolution history (Figure 9, B), in which the team members describe the many implications and design options for the exposed ductwork system, such as noise considerations and the architect's concerns over the detailing of the ductwork's exterior. Dan discovers that the architect chose to embrace the exposed ductwork as an*

expression of functional transparency, which was a theme of his design. The architect also decided to use the ductwork's ribs to echo the crenellated walls of the atrium's interior. As the Pacific University project is an engineering building, Dan had also chosen to use functional transparency as a primary theme. He doesn't like the ribs on the ductwork, however, and wants to know if there are other options. Bo finds a link on the UMC to the ductwork vendor, and opens it on the right screen (C). He locates a system that is available with a smooth surface, and opens a detail of the system on the screen in the center of the table (D).

- *While Bo and Dan explore the ductwork system, Andrea opens a new Overview Map on her laptop, which is registered as a CoMem-Villager. She searches for "floor height limitations" (Figure 10, D). In comparing it with the Map on which the original HVAC search was conducted (B), she finds that there are several projects in addition to the Coastal University and California Hotel projects in which floor height limitations appear to have been an issue. She opens a copy of the new Map on the left screen (A) and a UMC for a component with high relevance in the Bay St. Louis project on the right screen (C). This component details an under-floor HVAC system. They explore that option evolution using the EHE, PCE, and details in the CoMem-iRoom. Andrea proposes that the group explore it as another potential solution that they can compare with the exposed ductwork option. Dan and Bo agree, having been able to retrieve rich content, and explore and assess the options from the evolution of different alternatives.*

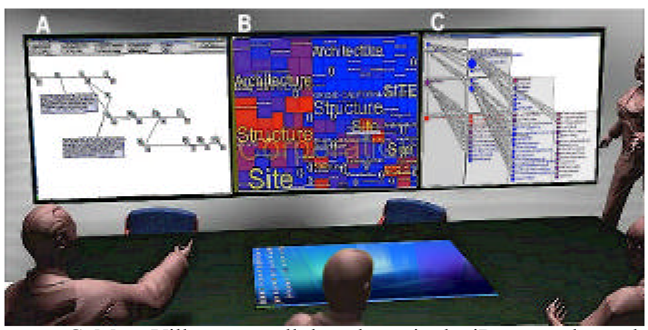

Figure 5: Andrea opens CoMem Villagers on all three hosts in the iRoom and searches for the Coastal HVAC design. CoMem EHE (A), Overview Map (B), and PCE (C) are displayed.

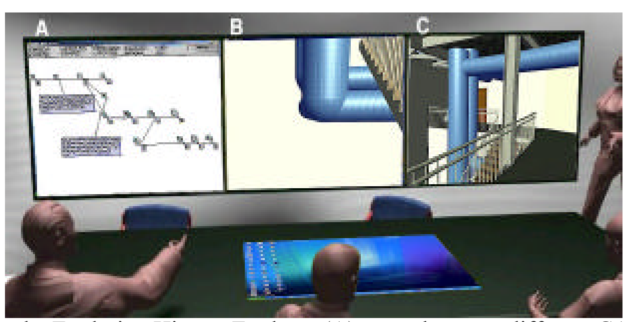

Figure 6**:** Dan uses the Evolution History Explorer (A) to explore two different CAD versions of the HVAC component's design development (B, C).

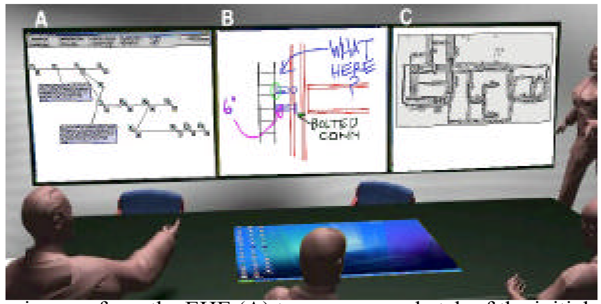

Figure 7: Bo opens images from the EHE (A) to compare a sketch of the initial exposed ductwork installation design (B) and a detail of the final installation (C).

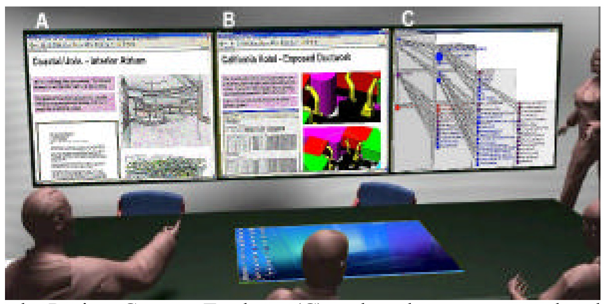

Figure 8: Dan views the Project Context Explorer (C) and explores content related to the atrium of the Coastal University project (A) and the exposed ductwork system of the California Hotel (B) project.

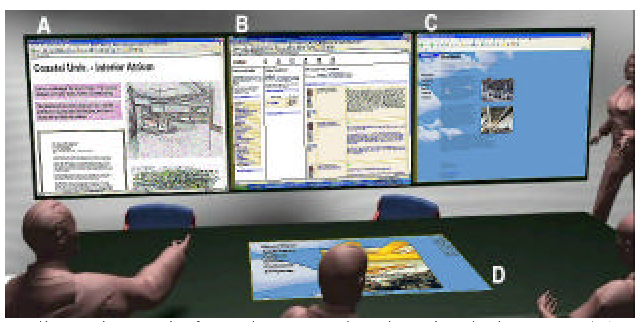

Figure 9: Dan opens a discussion topic from the Coastal University design team (B). Bo follows a link to the ductwork vendor website (C), and opens a detail of the vendor's smooth ductwork product (D).

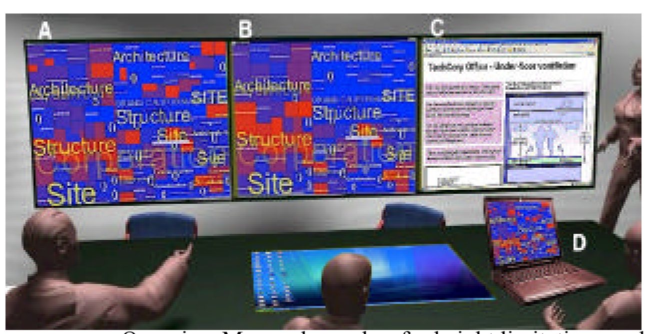

Figure 10: Andrea opens a new Overview Map and searches for height limitations on her laptop (D). She finds the results interesting, so she send the Map on a large display (A) and a UMC for an under-floor ventilation solution in the TechCorp Office project ib display (C).

4.2 Features and Benefits

This scenario highlights the primary features and benefits of the CoMem™-iRoom Architecture:

- Efficient exploration of an extensive content archive
- Communication of contextual information for design components and decisions
- Ability to easily browse multiple pieces of rich content simultaneously through utilization of numerous interlinked and interactive display areas
- Provided visibility of explored content to multiple participants, increasing the opportunities for group learning and chance discovery
- Dynamic adaptability to number of users and number of machines used by the group

5. Conclusions

Knowledge reuse involves a process of interactive knowledge exploration and visualization between A/E/C team-members. The state of practice, however, in such collaborative reuse is based on exploration of design content stored in corporate project archives and repositories that do not capture the design process and thereby result in loss of contextualized information.

We have identified the limitations constraining the current process of knowledge reuse through collaborative A/E/C teamwork to be primarily related to large amounts of content, decontextualization of that content through limited information and knowledge retrieval and difficulties in visualization of such rich content. We integrated CoMem™ with the iRoom architecture to deployed a number of CoMem™ -Villagers that can communicate such rich content over a set of networked hosts in a given iRoom architecture. We have demonstrated CoMem™ -iRoom as an effective workspace that provides a number of features in the aid of collaborative teamwork in support of knowledge reuse, thereby addressing these limitations. We have deployed a pilot CoMem-iRoom at Intel's Arizona headquarter, and have received positive feedback about its successful pilot implementation and affordances:

"[CoMem™ -iRoom] provides great benefits . . . [having] the actual context that the information was created in stored with the information makes reuse so much more powerful. Very powerful in its presentation of complete knowledge within context!"

-Chris Michaelis – Project Manager, Intel

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